

# **SPECIFICATION**

Title of the Invention :

**DIRECTION OF ARRIVAL ESTIMATOR  
AND  
DIRECTION OF ARRIVAL ESTIMATION METHOD**

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DIRECTION OF ARRIVAL ESTIMATOR AND DIRECTION OF ARRIVAL  
ESTIMATION METHOD

BACKGROUND OF THE INVENTION

5

Field of the Invention

The present invention relates to a direction of  
arrival estimator and direction of arrival estimation  
method for estimating the direction of arrival of a  
10 reception signal using an array antenna.

Description of the Related Art

As a method for improving the reception quality of  
a base station apparatus in a radio communication system,  
15 a method of estimating the direction of arrival of a  
reception signal with an array antenna incorporated and  
focusing directivity on a desired signal is proposed.  
Since a signal received by the base station apparatus  
includes a multitude of interference signals in addition  
20 to the desired signal, the base station apparatus needs  
to separate all signals included in the reception signal  
and select the desired signal in order to estimate the  
direction of arrival of the desired signal.

When the base station apparatus carries out radio  
25 communication with a plurality of terminal apparatuses  
using a spread spectrum signal, the base station  
apparatus can separate all signals included in the  
reception signal by carrying out despreading processing,

etc.

Here, there are cases where within the frequency band of a spread spectrum signal, a signal of a narrow frequency band is mixed with the spread spectrum signal  
5 such as a frequency-modulated signal and received by an antenna.

In this case, the base station apparatus cannot separate the spread spectrum signal, a desired signal, from the other signal, an interference signal, and  
10 therefore it is necessary to separate the desired signal from the interference signal in some way to estimate the direction of arrival of the desired signal.

However, no technology has been disclosed so far to distinguish the spread spectrum signal from a  
15 reception signal made up of the spread spectrum signal and a signal based on a modulation system different from that of the spread spectrum signal.

#### SUMMARY OF THE INVENTION

20 It is an object of the present invention to separate a spread spectrum signal from a reception signal made up of the spread spectrum signal and a signal based on a modulation system different from that of the spread  
25 spectrum signal and estimate its direction of arrival.

The present invention attains the above object by applying cyclostationarity of a modulated signal and selecting signals using a cycle frequency specific to

its modulation system. More specifically, the spread spectrum signal is detected by using a frequency determined from its chip rate as a cycle frequency, while signals other than the spread spectrum signal are  
5 detected through cyclic frequencies specific to those signals based on differences in the modulation system and transmission speed.

#### BRIEF DESCRIPTION OF THE DRAWINGS

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The above and other objects and features of the invention will appear more fully hereinafter from a consideration of the following description taken in connection with the accompanying drawing wherein one  
15 example is illustrated by way of example, in which;

FIG.1 is a block connection diagram of a direction of arrival estimator according to Embodiment 1 of the present invention;

FIG.2 is a block connection diagram of a direction  
20 of arrival estimator according to Embodiment 2 of the present invention;

FIG.3 is a block connection diagram of a direction of arrival estimator according to Embodiment 3 of the present invention; and

25 FIG.4 illustrates a positional relationship between array antennas of the direction of arrival estimator shown in FIG.4.

DETAILED DESCRIPTION OF THE  
PREFERRED EMBODIMENTS

With reference now to the attached drawings,  
5   embodiments of the present invention will be explained  
in detail below. By the way, the following embodiments  
assume that a spread spectrum signal is a desired signal,  
while a signal having a narrow frequency band with  
respect to the spread spectrum signal such as a frequency  
10   modulated signal and existing within the spread spectrum  
signal band as an interference signal.

(Embodiment 1)

FIG.1 is a block connection diagram of a direction  
15   of arrival estimator according to Embodiment 1 of the  
present invention. The direction of arrival estimator  
shown in FIG.1 is mainly configured by array antenna 101,  
frequency conversion section 102, A/D conversion section  
103, data storage section 104, correlation detection  
20   section 105, cycle frequency detection section 106,  
correlation detection section 107 and direction of  
arrival estimation section 108.

Frequency conversion section 102 converts the  
frequency of a signal received from a terminal apparatus  
25   by array antenna 101 to an intermediate frequency or  
baseband frequency. A/D conversion section 103  
converts the frequency-converted signal to a digital  
signal.

Data storage section 104 stores the digital signal output from A/D conversion section 103 until the number of spread spectrum signal chips reaches a predetermined amount (e.g., 100 chips) or more. Correlation detection  
5 section 105 uses the chip rate of a known spread spectrum signal as a cycle frequency and calculates a cyclic correlation matrix of the spread spectrum signals of data stored in data storage section 104.

Cycle frequency detection section 106 detects the  
10 cycle frequency of an interference signal using the digital signal output from A/D conversion section 103. Here, in the case where the interference signal is an amplitude-modulated signal or frequency-modulated signal, a frequency doubling the carrier frequency is  
15 detected as a cycle frequency, and in the case where the interference signal is a PSK signal, the symbol rate is detected as a cycle frequency. Thus, a cycle frequency specific to the signal depending on the modulation system and transmission speed is detected.

20 The method of detecting a cycle frequency by cycle frequency detection section 106 includes a method whereby a cyclic auto-correlation function is calculated by changing a cycle frequency using a digital signal made up of a reception signal of one antenna element, a maximum  
25 value of the cyclic auto-correlation row, which is the calculation result, is detected and a cycle frequency corresponding to the value is thereby detected.

Correlation detection section 107 uses the

detection result of cycle frequency detection section 106 as a cycle frequency and calculates a cyclic correlation matrix of the signal, which becomes an interference signal, using the digital signal output from A/D conversion section 103.

By the way, correlation detection section 105 and correlation detection section 107 use their respective cyclic frequencies and calculate a cyclic correlation matrix using a cyclic cross correlation row of the signal received by one antenna element versus a signal received by another antenna element as a row.

Direction of arrival estimation section 108 uses the cyclic correlation matrices calculated by correlation detection section 105 and correlation detection section 107 to calculate their respective eigenvalues and eigenvectors and estimates the directions of arrival of a spread spectrum signal and a signal, which becomes an interference signal.

The technique for estimating the direction of arrival using a cyclic correlation matrix is described in detail in "Detection of Direction and Number of Impinging Signals in Array Antenna Using Cyclostationarity" by Hiroyuki Tsuji et al. (Collection of Institute of Electronics, Information and Communication Engineers, '98/1 Vol.J81-B-II No.1 pp.19-28). Furthermore, it is possible to estimate the number of arriving signals by deciding the magnitude of an eigenvalue. In the case of a complex eigenvalue, the

magnitude is decided using its absolute value.

As shown above, the invention according to this embodiment uses cyclostationarity of modulated signals and can select signals using cyclic frequencies specific to the modulation system, making it possible to separately estimate the directions of arrival of a spread spectrum signal and a signal with a cycle frequency different from that of the spread spectrum signal that exist within a same frequency band.

(Embodiment 2)

FIG.2 is a block connection diagram of a direction of arrival estimator according to Embodiment 2 of the present invention. The components in the direction of arrival estimator in FIG.2 common to those in FIG.1 are assigned the same reference numerals as those in FIG.1 and explanations thereof are omitted.

The direction of arrival estimator in FIG.2 differs from that in FIG.1 in that cycle frequency detection section 201 detects a plurality of cyclic frequencies and  $M$  ( $M$ : natural number) correlation detection sections 202-1 to 202- $M$  are provided.

The method of detecting a plurality of cyclic frequencies by cycle frequency detection section 201 includes a method whereby a cyclic auto-correlation function is calculated by changing a cycle frequency using a digital signal made up of a reception signal of one antenna element, a plurality of peak values of the



cyclic auto-correlation row, which is the calculation result, is detected and cyclic frequencies corresponding to the values are thereby detected.

Correlation detection sections 202-1 to 202-M each  
5 calculate cyclic correlation matrices using a plurality of cyclic frequencies, which is the output of cycle frequency detection section 201 and a digital signal, which is the output of A/D conversion section 103.

Direction of arrival estimation section 108 uses  
10 the cyclic correlation matrices calculated by correlation detection section 105 and correlation detection sections 202-1 to 202-M to calculate their respective eigenvalues and eigenvectors and estimates the directions of arrival of the spread spectrum signal and all signals, which become interference signals.  
15

Thus, the invention of this embodiment can separately estimate the directions of arrival of a spread spectrum signal and a plurality of signals with a cycle frequency different from that of the spread spectrum  
20 signal that exist within a same frequency band.

### (Embodiment 3)

FIG.3 is a block connection diagram of a direction of arrival estimator according to Embodiment 3 of the  
25 present invention. The direction of arrival estimator in FIG.3 differs from that in FIG.1 in that N (N: natural number) array antennas 101-1 to 101-N, N frequency conversion sections 102-1 to 102-N, N A/D conversion

sections 103-1 to 103-N, N data storage sections 104-1 to 104-N, N correlation detection sections 105-1 to 105-N, N cycle frequency detection sections 106-1 to 106-N, N correlation detection sections 107-1 to 107-N and N  
 5 direction of arrival estimation sections 108-1 to 108-N are provided and estimation result comparison section 301 is added.

FIG.4 illustrates a positional relationship between array antennas 101-1 to 101-N of the direction  
 10 of arrival estimator shown in FIG.3. As shown in FIG.4, N array antennas are installed in such a way that the direction of the normal to each array antenna forms an angle of  $360^\circ / N$  with the direction of the normal to its adjacent array antenna.

15 Array antennas 101-1 to 101-N each receive a signal from terminal apparatus 401. Then, the direction of arrival is estimated according to the method described in Embodiment 1 using the reception signals of the respective array antennas. Estimation result  
 20 comparison section 301 compares the estimation results of direction of arrival estimation sections 108-1 to 108-N.

Here, suppose the direction of the normal to array antenna 101-1 is decided as direction  $0^\circ$ . Then, based  
 25 on this array antenna 101-1, corrected angles of array antennas 101-1 to 101-N are decided from the directions of the normal to array antennas 101-1 to 101-N.

Estimation result comparison section 301 corrects

the estimation results of direction of arrival  
estimation sections 108-1 to 108-N with the corrected  
angles of their respective array antennas and thereby  
estimates the angles with respect to the direction of  
5 the normal to array antenna 101-1 and estimates their  
true directions of arrival for all directions by  
comparing the estimation results.

Thus, this embodiment can separately estimate the  
directions of arrival of a spread spectrum signal and  
10 a signal of a cycle frequency different from that of the  
spread spectrum signal that exist within a same frequency  
band for all directions.

As shown above, in the case where a signal having  
a wide frequency band such as a spread spectrum signal  
15 and a signal different from the spread spectrum signal  
coexist within the frequency band of the spread spectrum  
signal, the present invention can estimate the  
directions of arrival of the respective signals  
separately.

20 The present invention is not limited to the above  
described embodiments, and various variations and  
modifications may be possible without departing from the  
scope of the present invention.

This application is based on the Japanese Patent  
25 Application No. 2000-139994 filed on May 12, 2000, entire  
content of which is expressly incorporated by reference  
herein.